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Increasing Situational Awareness by Visualizing Uncertainty

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ABSTRACT

There are many sources of data available to enhance commanders' situational awareness. Whether the mission is war fighting, stability operations, or the defense of the homeland, decisions must be made based on the information available. Information comes from many varied sources, in many formats, with a continuum of validity, and is presented in a variety of ways. Situational awareness and decision superiority opportunity is increased when relevant data is effectively presented in a timely manner and with a measure of confidence. Exact, precise data is easier to present than uncertain data; but often uncertain data may be enough for a decision, based on rules of engagement and the value of the action to the mission. We have developed visualization techniques that focus on uncertainty for the purpose of providing decision-quality command and control information for both ground-based and airborne applications. A key focus of our work is to manage the visualization techniques so they do not clutter the display, as a cluttered display can actually decrease situational awareness by masking relevant information.

Data can be presented on a 2D or 3D visual display. This paper proposes a method for managing 2D visualizations to increase situational awareness.

Keywords: Interaction Techniques, Command and Control, Uncertainty, Movement Prediction

INTRODUCTION

In order to wage a successful campaign, next generation commanders and air controllers will need to assimilate a tremendous amount of available information, from a wide variety of sources and types ranging from hardcopy HUMINT reports to real-time sensor feeds. Armed with this data they will be expected to see through the "fog of information" and make time-critical decisions and to quantify the effects of those decisions, all in the face of uncertainty and risk. It is a daunting task for which systems and tools available to current command centers and airborne control platforms offer no proven solution. It is inarguable that decision support systems for any domain are dramatically improved by the addition of some degree of visualization. To date, however, even the most state-of-the-art visualization approaches concern themselves primarily with visualization of data; e.g., terrain, maps, iconic depictions of threat lay-downs and flight packages, etc. But data is not information, and it is information that the commander needs to gain the decision superiority required to successfully wage his campaign or for the airborne controller to gain the situational awareness needed to attain dominance of the airspace.

Much of Command, Control, Communications, Computers and Intelligence (C4I) deals with

making decisions in the face of uncertain or inadequate data. "Uncertainty can be generally defined as an inability to determine a variable value or system state (or nature) or to predict its future evolution." [CBP, p. 249] Reducing uncertainty (fog of war) and in the process increasing confidence in the validity of the information increases situational awareness. "There are four sources of 'fog' commanders and staffs must overcome to achieve accurate situational understanding: inadequate or poor-quality information; misinterpretation of information; conflicting information or choices; and too much information" [FM]. Many visualization techniques are developed in isolation to address only one or two sources of fog. A visualization approach is required in which individual techniques work together in a unified fashion to address all four sources of fog.

In the following sections, we categorize the types of threat location and movement data and discuss possible visual representations. We will explain how an effective interface can prevent these representations from becoming a cluttered and unusable visual barrage of data, and how our visualization tools can better interact in a complex system. We conclude with a discussion of related products

VISUALIZATION GOALS

The goal of visualization tools is not to fuse data, improve estimates, collaborate multiple information sources, etc. These are crucial tasks, and the visualization tools must accept and accommodate the data from these steps, but the goal of visualization is to display the data in such a way as to aid decision makers and to increase their situational awareness. According to the NATO Code of Best Practice, "assessments should be judged by their ability to reduce uncertainty" [CBP, p. 252], and this is also a very good metric by which to judge decision support visualizations.

Visualization is often a quick method to communicate information. "Communication is about giving the receiver of a message a right impression, not about formulating a statement that is formally correct on its own." [CBP, p. 262] "Visualization techniques will be helpful in this regard since they are usually more powerful than verbal reference to abstract concepts" [CBP, p. 263]. This will prove even more true in collaborative coalition environments where participants may have different native languages. In Alberts and Hayes, collaboration is one of the key dimensions of flexibility for situational awareness. [AH, p. 148]

One technique for reducing uncertainty is to provide visualization tools for managing the data. Tools that solve one source of fog at the expense of another are inadequate. Our techniques work together in a unified fashion to address all four sources of "fog". A key focus of our work is to manage the visualization techniques so that they do not clutter the display, and thus in turn contribute to the fog of war through the fourth source "too much information".

Operators are overwhelmed with command and control information; their screens becoming quickly cluttered, potentially obscuring important data. The system goal is to provide advanced, multi-sensory, display management concepts and algorithms for visualizing command and control information in simulated environments. Not all display management techniques are appropriate at all times. MÄK's visualization toolkits are designed as a set of display techniques. From this set, the appropriate subset of tools can be chosen based on criteria such as the situation, role of the user, or even the personal decision-making techniques of the commander or staff. These tools can be used to build flexible, customizable displays. Five key techniques were considered:

- **Tailoring the Display.** Based on the situation, user's role, individual user preferences and screen size (hand-held, desktop or data wall).
- **De-cluttering.** Focus on important information by providing the ability to filter out detail unnecessary to the task at hand. Techniques interoperate with each other in a dynamic environment.
- **Integration.** Fluidly change visualization techniques as the situation evolves.
- **Cross tool control.** All visualization tools can show alternate views of the same situation, or views can be set and controlled by one for the others.
- **Use of Toolkit.** Easy to extend techniques and customized displays to support future efforts.

ORGANIZATION

Knowledge Organization

We can coarsely categorize each piece of the battle space into three types: areas where we have no presence and hence no data collection capability, areas where we have collection coverage and no threat data is reported, and areas where we have coverage and have collected threat data. Identification of each of these areas provides different benefits.

One of the most extreme examples of "inadequate information" is no information at all, or a *knowledge void*. By simply and easily identifying regions of the battle space where we do not have any collection capability, commanders can make more informed decisions about where to put emphasis in collection plans.

The second category, areas where we have coverage but have not collected threat data, is also useful to identify. These areas are potentially good places to plan supply and evacuation routes, or to covertly maneuver friendly forces or stage into strategic positions. Conversely, the reason for lack of threat data in this region may be the result of inadequate collection coverage. Visualization can provide a confidence factor on the coverage to provide commanders with a measure of validity.

The third category, areas where threat data has been collected, is the most prone to clutter. Collected data may be inadequate or conflicting. Commanders spend most of their time dealing with this data so we provide interactive techniques and tools for the operator to manipulate this data. The operator can use the tools in such a way as to filter out non-impact data, present relevant information, apply a confidence value to the data and then display that data to decision makers.

Visual Organization

Overlays correspond to traditional acetate sheets overlaying a terrain map, upon which one can draw. Any symbol can be placed on an overlay layer. Through the overlay manager, individual overlays can be dynamically created, toggled on or off, or even reordered.

For a user specified area of interest, we generate a 2D overlay that indicates the areas where there is collection coverage. We will also generate the inverse; an overlay that marks the areas where we have no data from any source, i.e. the knowledge voids (this is not fully

implemented). We can further divide the area of coverage to show areas where threat reports have been received, and those where they have not.

The areas of coverage on an overlay may be drawn as semi-transparent, or with a variety of patterned fills such as crosshatches or stripes. Unlike solidly filled blocks, this allows details of the battle space to remain available to the commander. From a pragmatic point of view, transparencies provide a better user interface, but patterned fills are faster to render on a display (since they do not require alpha blending). The decision of which to use will be based on the number and size of the objects displayed, and frame update requirements. Hence allowing the user to choose the display technique is important to overall system usability.

Coverage areas may be drawn in any color. Although standard defaults are easiest to recognize and use, color changes may be necessary to provide contrast against different terrain map backgrounds.

Further refinements would include the ability to distinguish areas of coverage by source, such as sensor type. Each source type could be placed on a separate overlay and/or encoded with different colors. This would allow the user to interactively toggle each one (or its inverse) on or off, and to see them individually or in groups. This could easily display the coverage of individual systems such as AWACS, JSTARS, COMPASS CALL, RIVET JOINT, U-2, UAVs, PATRIOT batteries, or to see all air defense coverage and assets or all passive collection assets. By placing the display of these overlays under user control, we avoid cluttering the battlefield map when the data is not useful, more specifically; we avoid the fourth problem "too much information".

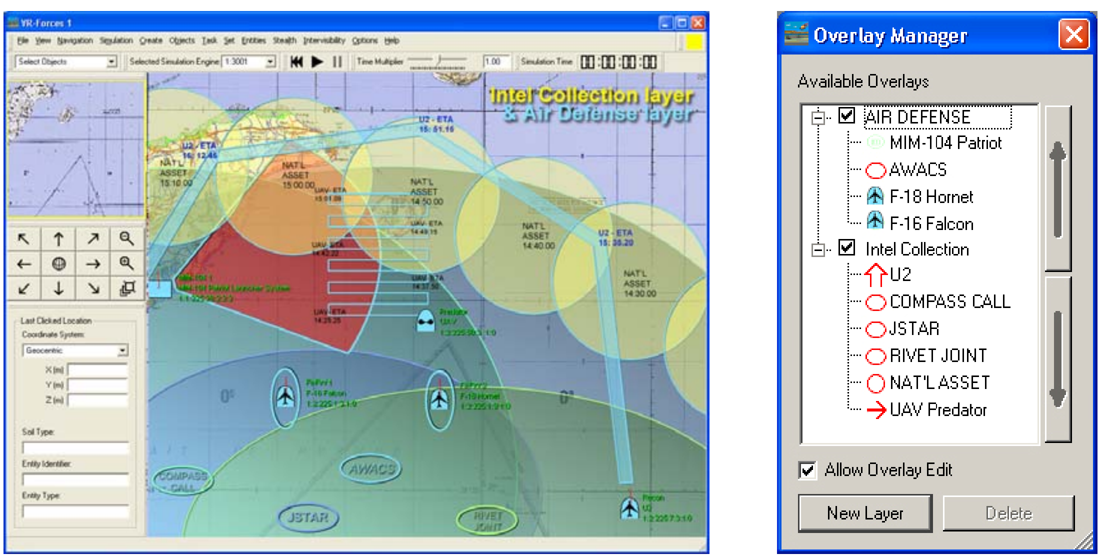

Figure 1 The overlay manager (right) is used to turn on both air defense and Intel collection overlay layers. With all data shown at the same time, the screen (left) is so cluttered that it is difficult to understand the situation.

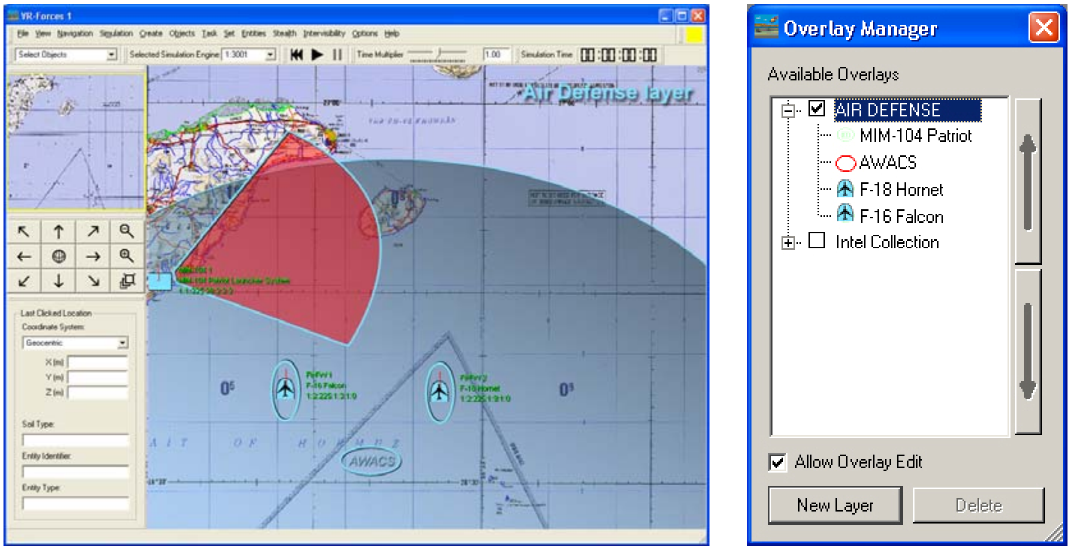

Figure 2 With only the Air Defense overlay layers shown; it is easier to comprehend the situation

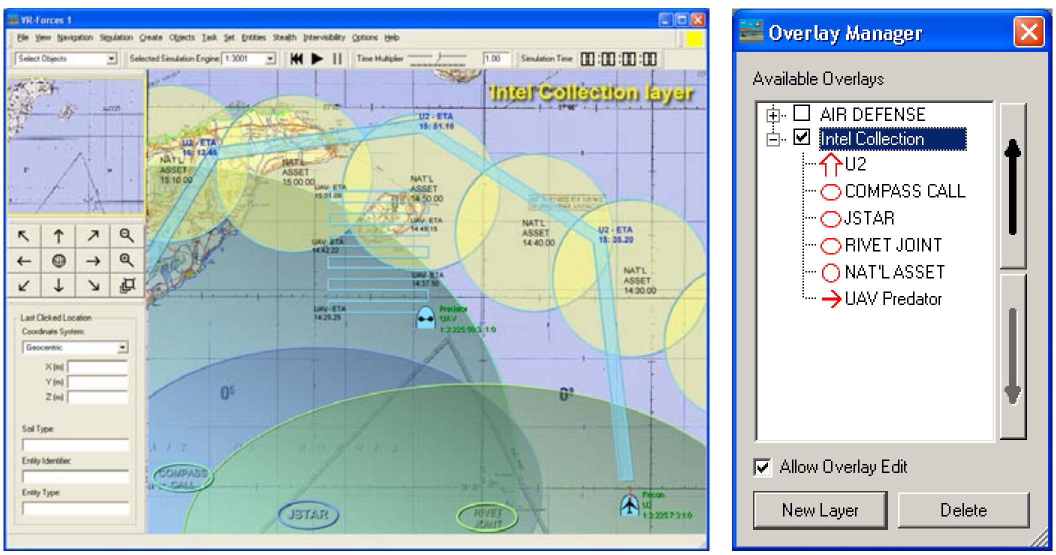

Figure 3 With the Air Defense layers turned off, the Intel collection becomes more apparent.

DATA UNCERTAINTY

Verification and Consolidation of Threat Data

There are many sources of data available to commanders. Another source of uncertainty arises from the quality and consistency of these data sources.

Information collected may be inadequate (saw something, but not sure of the number or type), conflict with one another (if multiple units have different view points, they may each see something different, none of which may be entirely accurate), be misleading due to temporal discrepancies (two reports at different times of the same area), simply be too old, or be corrupt.

Data corruption may be accidental through transmission failure or intentional through hostile acts, where the enemy actively intercepts, alters or destroys data. The first step in resolving the uncertainty is to be able to organize and access the data in a meaningful way. Two types of organization are time and space. Creating threat icons in the locations specified in reports, the commander gains a spatial overview of the data. Providing the operator the capability to apply a collection time stamp and the ability to provide a confidence value allows the decision maker to quickly form an impression of the timeliness and validity of the data.

There may still be ambiguity and uncertainty, since multiple sightings will result in multiple threat reports, and there is no way to distinguish between two friendly units sighting the same threat unit and have the same friendly units sight different opposing force units. One method for dealing with the data quality is to provide extra information, but structured in such a way that it does not overwhelm the display. A user selects an area of interest (AOI) within the battle space to query the collection sources. A list is displayed, showing how the information was collected and where and when the collection took place. For example, multiple tanks could have seen that sub-area, as well as a UAV. To assist decision makers, again, a time stamp and confidence value can be attached to the icon.

Visual Representation of Source Data

A side panel shows additional pertinent data for selected list items. For example, report time, externally determined confidence ratings of the source data, frequency (for sensors), or external forces that could affect the accuracy of the report such as weather. A "show view" button could pop up an inset window to show what that entity "saw" from that entities viewpoint. If available, UAV video or still images from any source could be inserted.

Having the tools to display selected data, apply a confidence value, apply a collection time stamp, and manage the data on the screen allows the operator to better present the situation. Based on this enhanced human understanding of the battle space, the operator can use our visualization tools to interact with the system and clarify the display for decision makers.

One such action available is to move objects from the 2D display to a “lost contact” list. This action is appropriate when one report indicates an enemy presence in an area, but a later report does not see that unit. In this case we know the unit has moved, so we do not want to show the icon in that area, but we certainly do not want to forget about that opposing force unit.

Another visualization capability is designed to indicate areas covered within a certain time period. For example, although we don't have a current collection asset in a certain part of the battle space, if a sensor covered the area previously or will cover the area later, a time stamp on the collection track or area would inform the decision maker of the area collection status. Visualization tools are provided to allow commanders to see at a glance, and be able to filter, various collection and weapon system coverage, sensor tracks, and airspace coordination measures.

INTERACTION OF VISUALIZATION TECHNIQUES

The goal of the interface is to simultaneously provide access to all of the types of data and provide the operator tools to enhance the value of the information and prevent the volume of

data from overwhelming the decision maker. Thus, we propose the following list as suggestions for enhancing the display:

- One source type per overlay, plus a universal overlay switch which, for convenience, turns all overlays on or off as a block.
- Display sensor coverage for a period of time specified in a user modifiable configuration file. Each type of sensor may have a different time period specified. For example, days for satellites, hours for planes, last hour for DI. This will also allow the user to configure for different types of combat.
- Allow the user to set the period of time on a slider, from the maximum specified to immediate. That way the user can dynamically determine the coverage over the time period of interest.
- Allow coverage segments to be created based on altitude intervals. For example, coverage under 1000 ft.
- Terrain projection. Project sensor coverage on to the terrain. Clearer picture of areas that have been covered.
- Allow the operator the capability to apply a time stamp and confidence value to any displayed icon.

TOOL INTERACTION

MÄK has 3 visualization tools: the MÄK Plan View Display (2D tactical map display), the MÄK Stealth (traditional, realistic 3D viewer), and the MÄK StealthXR (3D viewer which also displays non-realistic data such as 2525B icons, NCBR (nuclear, chemical, biological, radiological) hazards, satellite imagery, threat domes, etc).

These three visualization products inter-operate and are commercially available and supported on a variety of platforms. The StealthXR is a new product that has recently been launched. The PVD and Stealth are mature products. All products natively support HLA and DIS, while plug-in APIs can be tailored to import entity locations and tracks from various C4I protocols. All products support a variety of terrain formats, raster maps and vector data. All products have been run on desktops and large screens. To date, only the 2D PVD has been run on a hand-held device, although we see no barriers to supporting 3D on a hand-held.

RESULTS AND FUTURE WORK

The USAF contract under which this work has been done is still not completed. The work will be integrated into our products, and made available as part of a commercial off the shelf (COTS) toolkit. As such, this paper refers to a commercial product whose on-going development and maintenance will continue for many years. Many of our plans are based on preliminary feedback from subject matter experts and trade show demonstrations, but will change with additional feedback (such as that hopefully generated by this paper). Current plans include:

- Saving individual preferences for visualization techniques, such as which overlays are by default on or off etc.
- Implementing a variety of techniques to distinguish confidence levels for individual data points.

- Allowing filtering by confidence levels. For example, show data reported by sources with reliability ratings of 70% or higher.
- Implementing the inverse coverage display (knowledge voids).
- Adding some of the proposed visualization interaction techniques.

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Much of the 2D work was done under a DoD small business innovative research program (SBIR) with the army (CECOM). The 2D work was extended, and 3D work enhanced through another SBIR with AFRL (Air Force, Rome Labs). The first contract is complete, the latter ongoing. Other funding sources were internal product development.

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